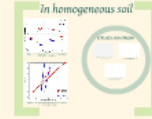
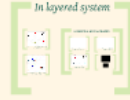
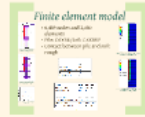


Computational Modeling of the Load Transfer Mechanism in a Heat Exchanger Pile

Tri V Tran*, Dunja Peric**

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 ** Associate Professor, Department of Civil Engineering, 2111 Fiedler Hall, Kansas State University, Manhattan, KS 66502-2000



Introduction

Heat exchanger piles are a type of pile foundation that can transfer both vertical and lateral loads. They are commonly used in offshore structures, bridges, and industrial facilities. The design of heat exchanger piles involves considering the interaction between the pile and the surrounding soil, as well as the thermal effects of the heat exchanger.

Objective

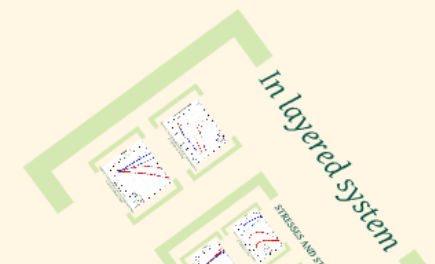
The objective of this study is to investigate the load transfer mechanism in a heat exchanger pile. The study will focus on the interaction between the pile and the surrounding soil, as well as the thermal effects of the heat exchanger.

Computational Modeling of the Load Transfer Mechanism in a Heat Exchanger Pile

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Outline

- Introduction
- Objective
- Background
- Finite element model
- The behavior of the HEP in homogeneous soil
- The behavior of the HEP in layered system
- Conclusions



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Outline

- Introduction
- Objective
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- Finite element model
- The behavior of the HEP in homogeneous soil
- The behavior of the HEP in layered system
- Conclusions

Introduction

- Ground source heat exchange (GSHE) system
- Reinforced concrete pile
- Previous full scale field studies

| No. of case | Author / Year | Location of the project |
|--------------------|------------------------------------|--------------------------------|
| 1 | Laloui et al. (2006) in [1] | Lausanne / Switzerland |
| 2 | Brandl (2006) in [2] | Bad Schallerbach / Austria |
| 3 | Bourne-Webb et al. (2009) in [3] | Lambet College / London |
| 4 | McCartney and Murphy (2012) in [4] | Denver / Colorado |
| 5 | Murphy et al. (2014) in [5] | US Air Force Academy |
| 6 | Sutman et al. (2014) in [6] | Richmond / Texas |

Table 1. Previous studies on full scale field experiments on HEP

Objective

- Investigate the mechanical behaviors of an energy piles.
- Investigate the effects of soil layering and stiffness on the behavior of energy piles.
- Evaluate the displacement, stresses and strains of the pile during heating and cooling cycles.

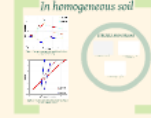
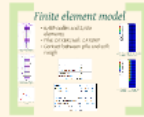
Background

- Null point
- Sign convention: upward displacement, upward shaft friction, expansive strain and tensile stress are positive
- The free thermal strain: $\epsilon_{T-Free} = \alpha \Delta T$
- Additional stress: $\sigma_T = E (\epsilon_{T-O} - \epsilon_{T-Free})$

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Background

Heat exchanger piles are a type of ground source heat exchanger (GSHE) that use the ground as a heat sink or source. They are typically used in buildings for space heating and cooling. The background section discusses the importance of understanding the load transfer mechanism in these piles.



Introduction

Heat exchanger piles are a type of ground source heat exchanger (GSHE) that use the ground as a heat sink or source. They are typically used in buildings for space heating and cooling. The introduction section discusses the importance of understanding the load transfer mechanism in these piles.

Objective

The objective of this study is to investigate the load transfer mechanism in heat exchanger piles. The study aims to determine the effect of pile length, pile diameter, and pile spacing on the load transfer mechanism.

Finite element model

- 6,489 nodes and 2,080 elements
- Pile: CAX8R; Soil: CAX8RP
- Contact between pile and soil: rough

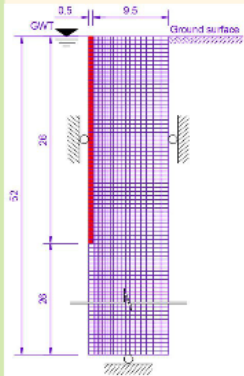


Figure 4. FE model and boundary conditions in a homogeneous soil

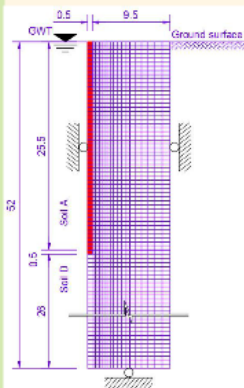


Figure 5. FE model and boundary conditions in a layered system

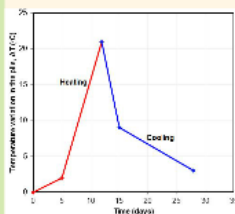


Figure 6. The history of temperature imposed on the pile

| Property | Reinforced concrete pile |
|--|--------------------------|
| Young's modulus, E (MPa) | 29,200 |
| Poisson's ratio, ν | 0.177 |
| Density, ρ (kg/m ³) | 2,500 |
| Coefficient of thermal expansion, α (°C ⁻¹) | 1x10 ⁻⁶ |
| Heat capacity, C (J/m ³ °C) | 2x10 ⁶ |
| Thermal conductivity, λ (W/m °C) | 2.1 |

Table 2. Reinforced concrete pile properties

| Property | Soil A | Soil B | Soil D |
|--|---------------------|---------------------|---------------------|
| Bulk modulus, K (MPa) | 113.10 | 983.33 | 1,860 |
| Shear modulus, G (MPa) | 77.87 | 19.80 | 1,675 |
| Poisson's ratio, ν | 0.177 | 0.49 | 0.157 |
| Mass density, ρ (kg/m ³) | 2,500 | 2,000 | 2,550 |
| Coefficient of thermal expansion, α (°C ⁻¹) | 1x10 ⁻⁶ | 1x10 ⁻⁴ | 1x10 ⁻⁶ |
| Heat capacity, C (J/m ³ °C) | 2.4x10 ⁶ | 2.4x10 ⁶ | 2.0x10 ⁶ |
| Thermal conductivity, λ (W/m °C) | 1.8 | 1.8 | 1.1 |

Table 3. Soil properties

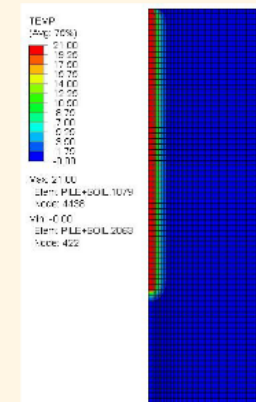


Figure 7. The distribution of temperature at the end of heating phase

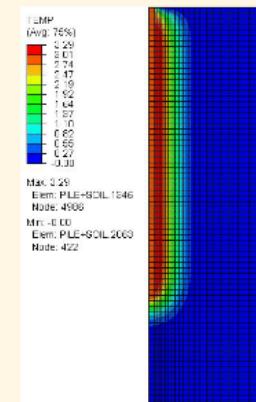


Figure 8. The distribution of temperature at the end of cooling phase

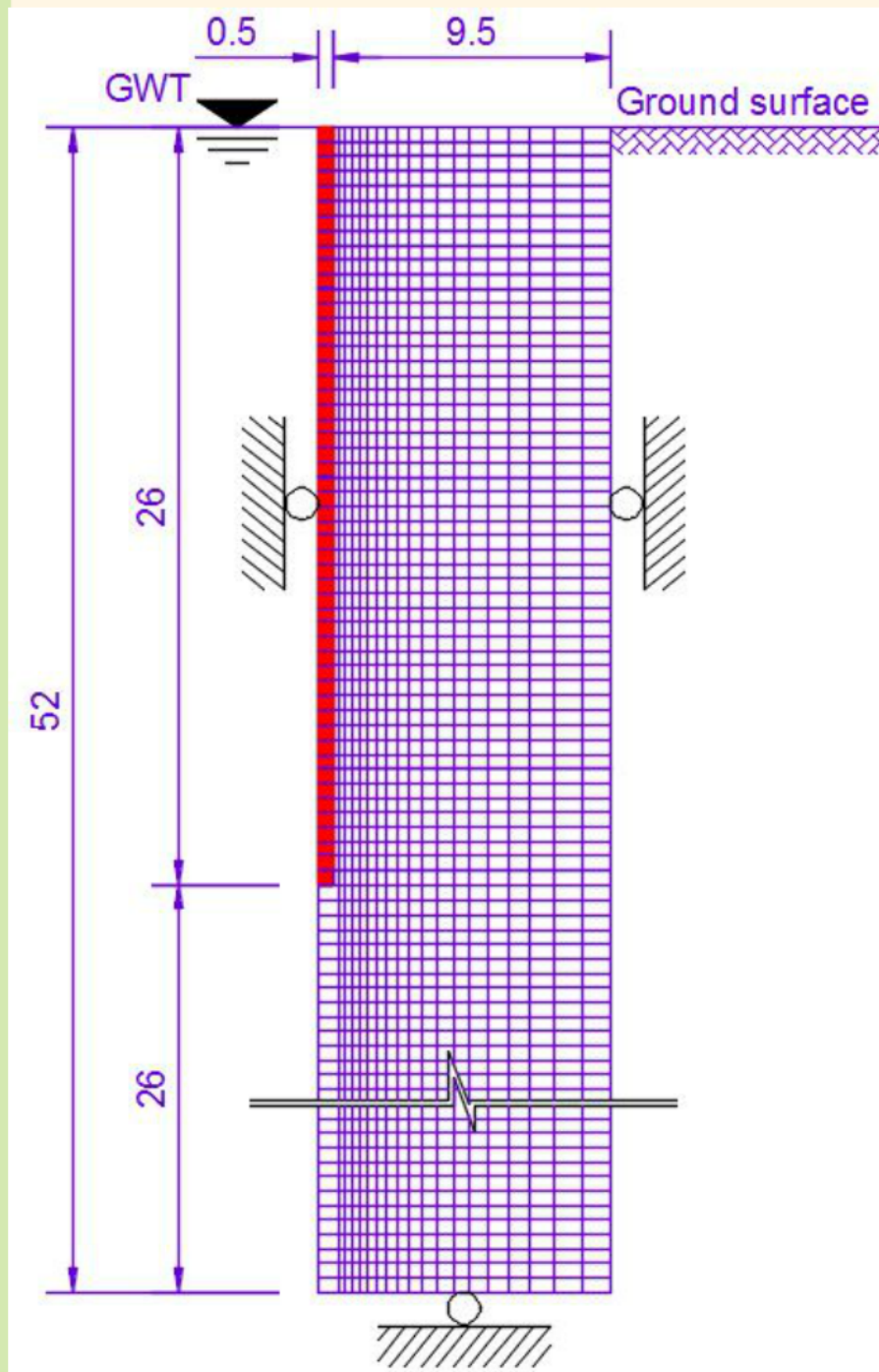


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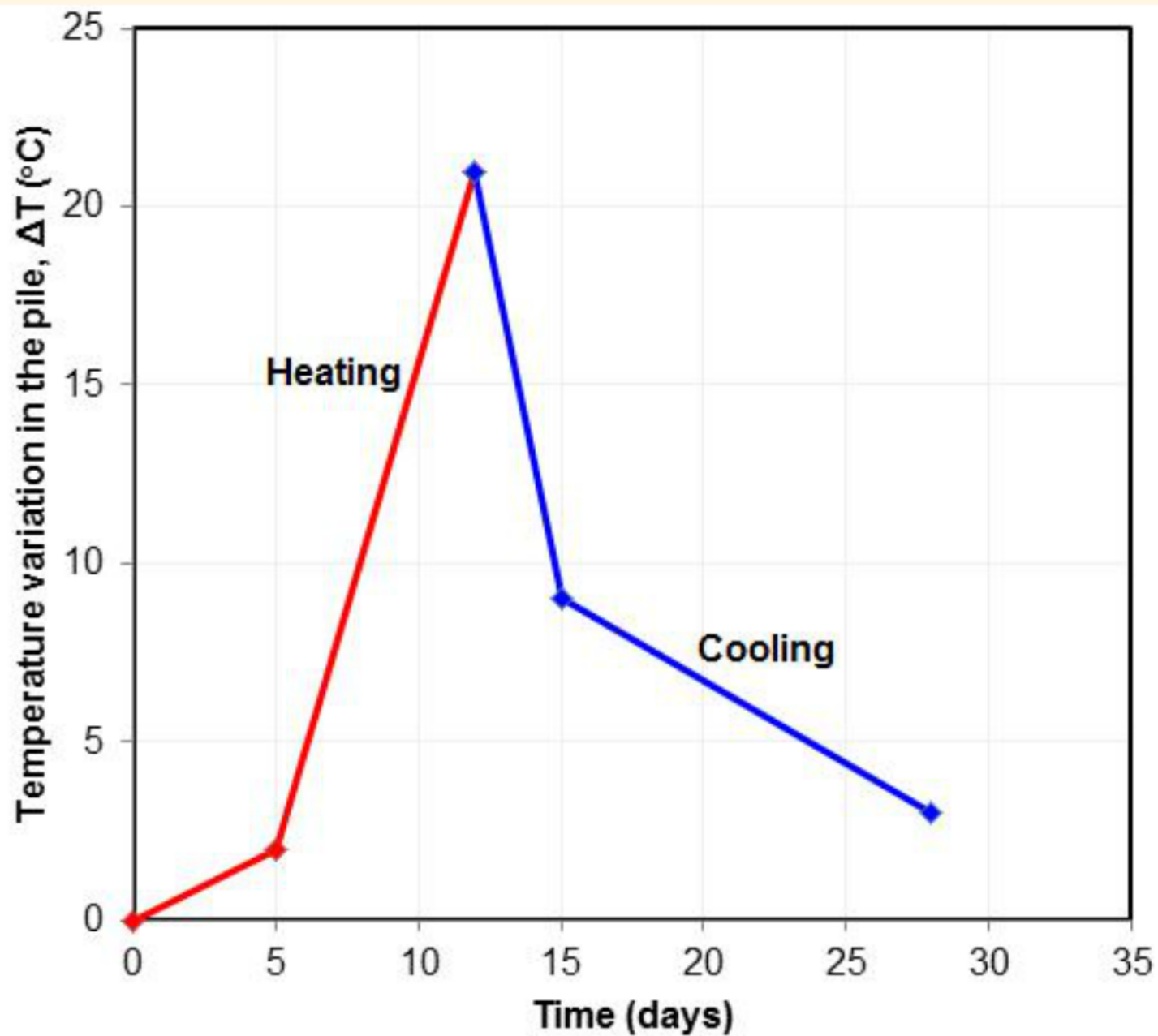


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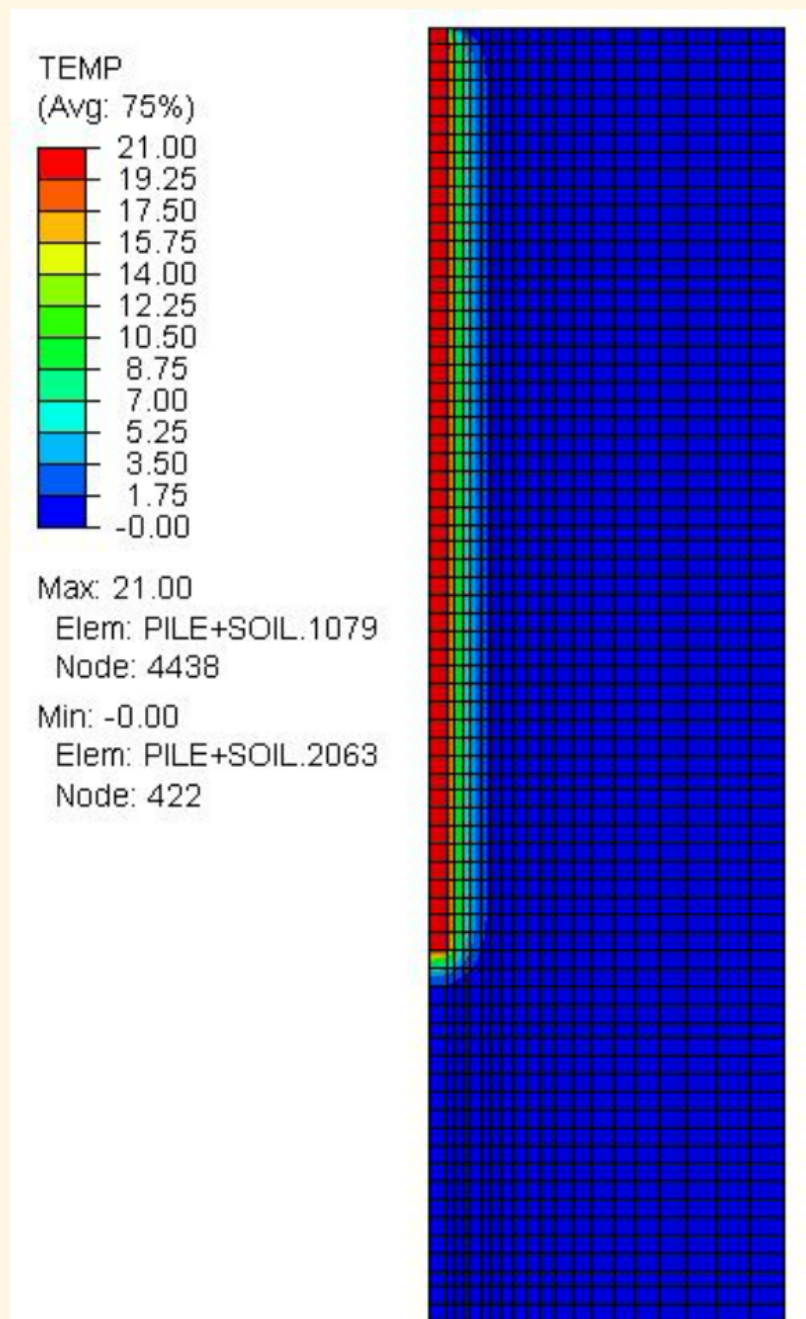


Figure 7. The distribution of temperature at the end of heating phase

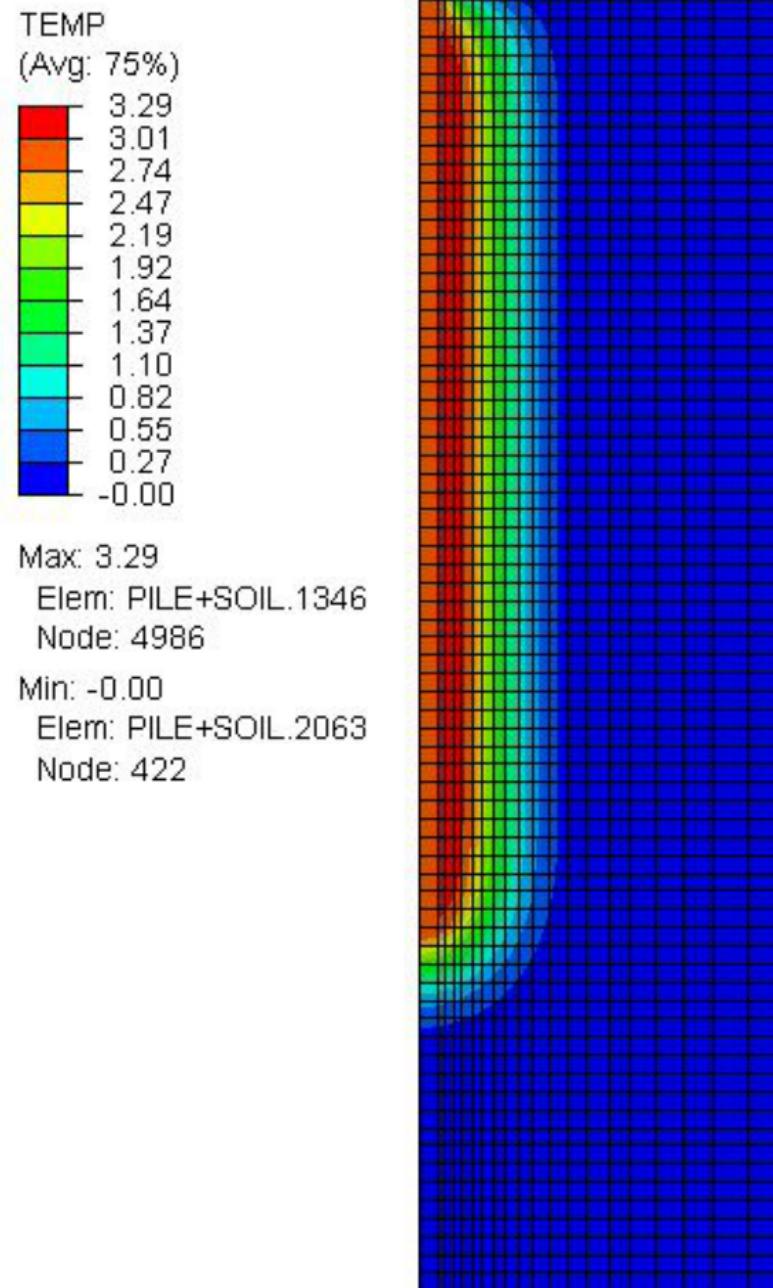


Figure 8. The distribution of temperature at the end of cooling phase

In homogeneous soil

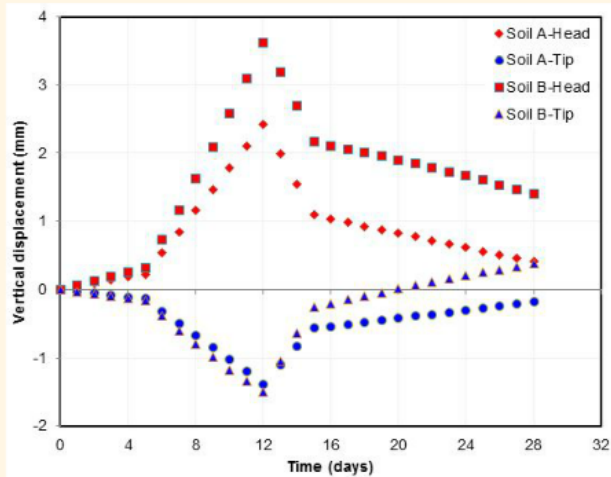


Figure 9. Vertical displacement of the pile head and toe during thermal loading

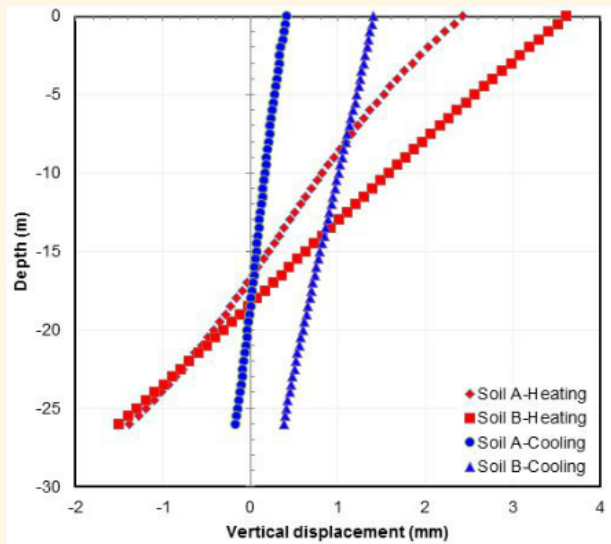


Figure 10. Vertical displacements of the pile with depth at 21 and 3 degree Celsius

STRESSES AND STRAINS

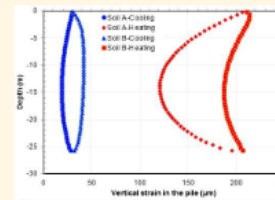


Figure 11. Vertical strains in the pile with depth at 21 and 3 degree Celsius

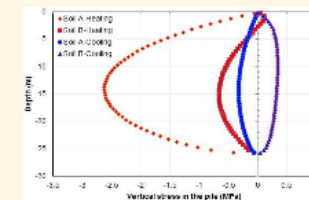


Figure 12. Vertical stress in the pile with depth at 21 and 3 degree Celsius

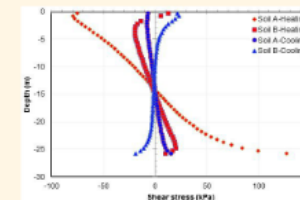


Figure 13. Shear stress next to pile with depth at the end of heating and cooling phases

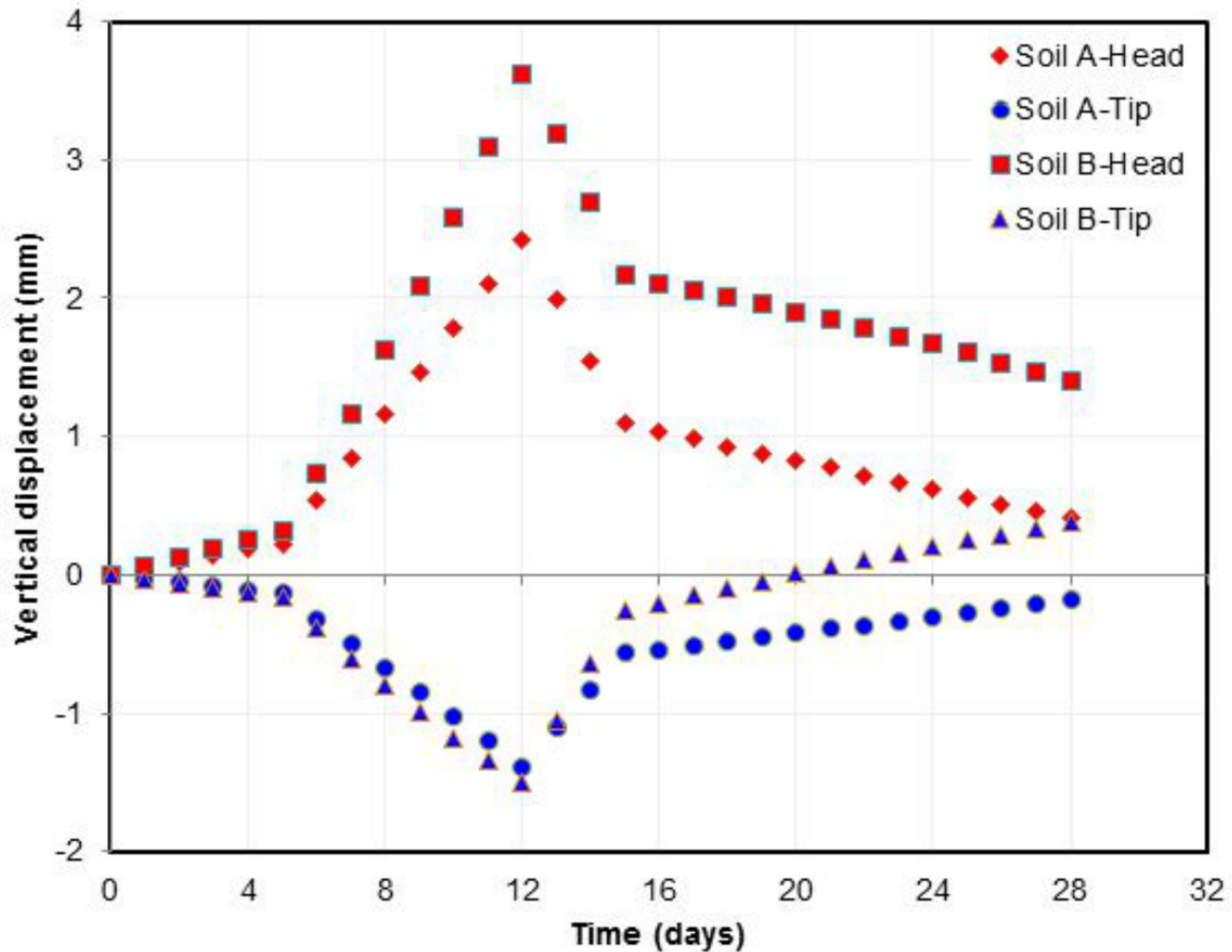


Figure 9. Vertical displacement of the pile head and toe during thermal loading

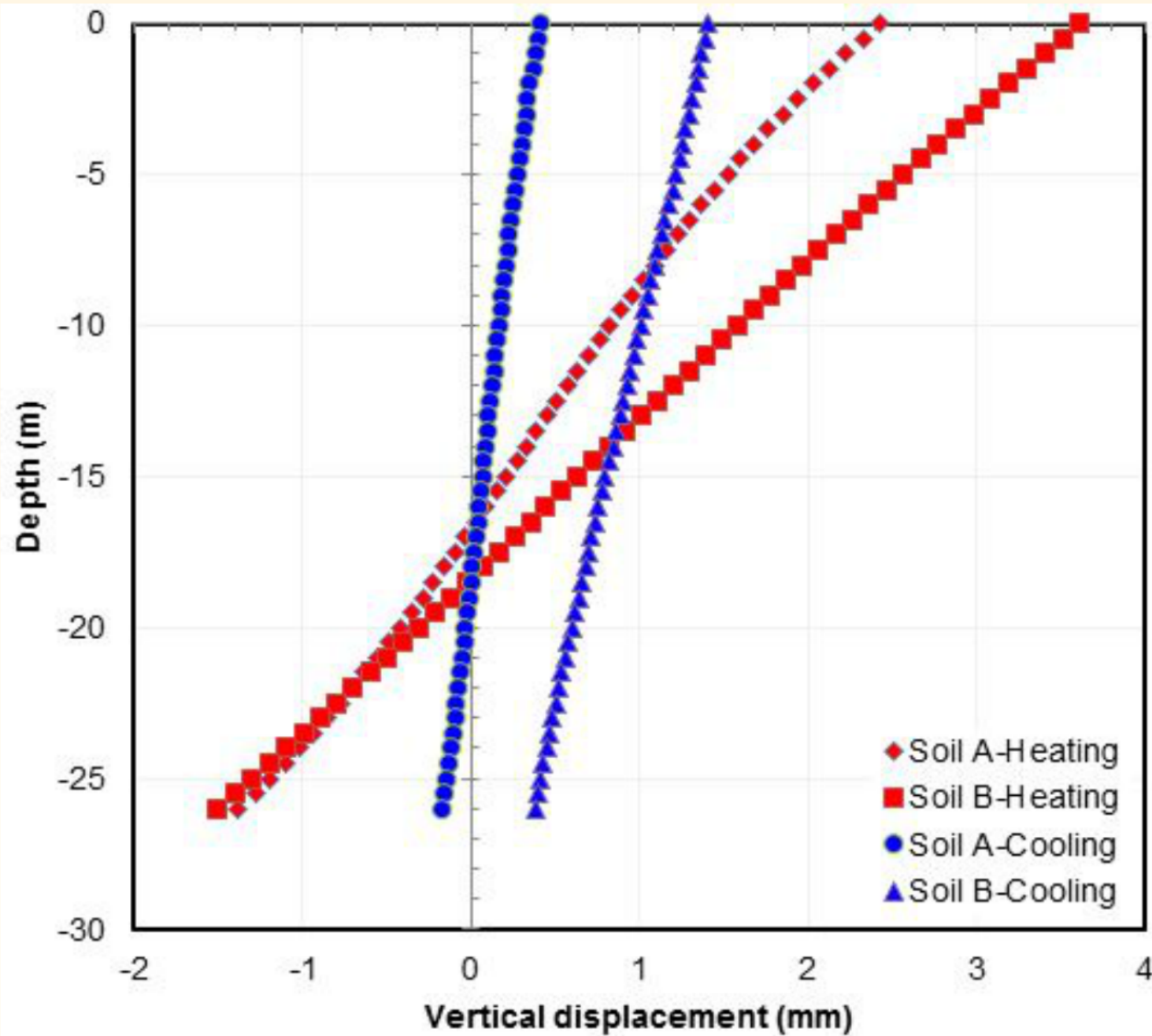


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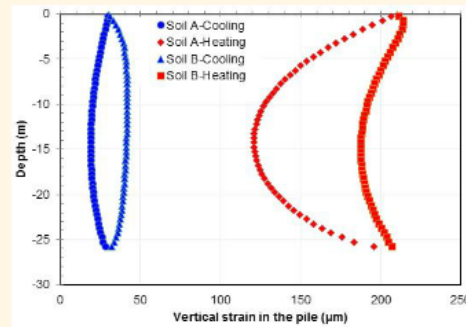


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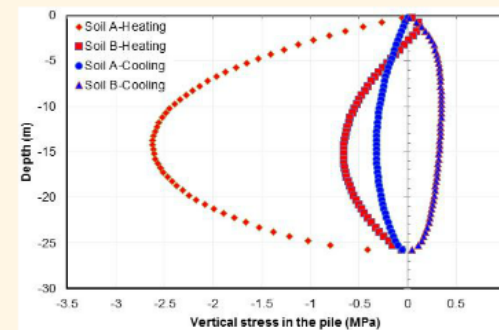


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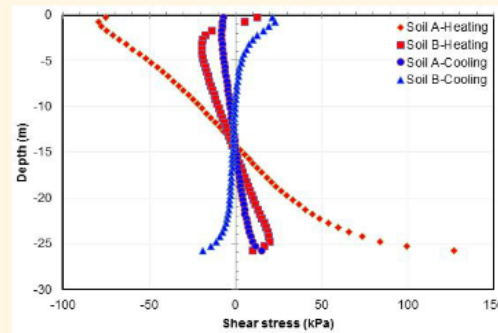


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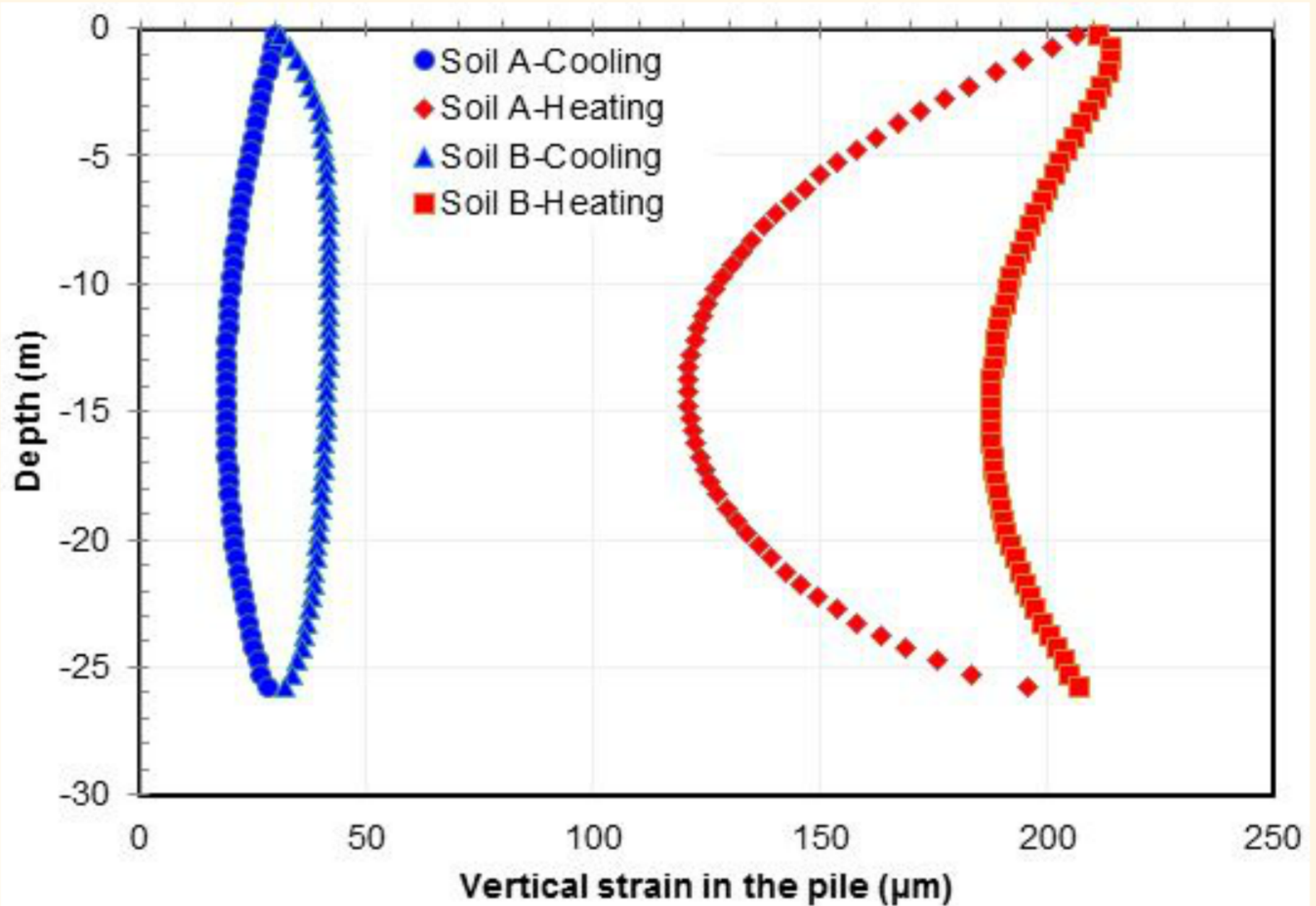


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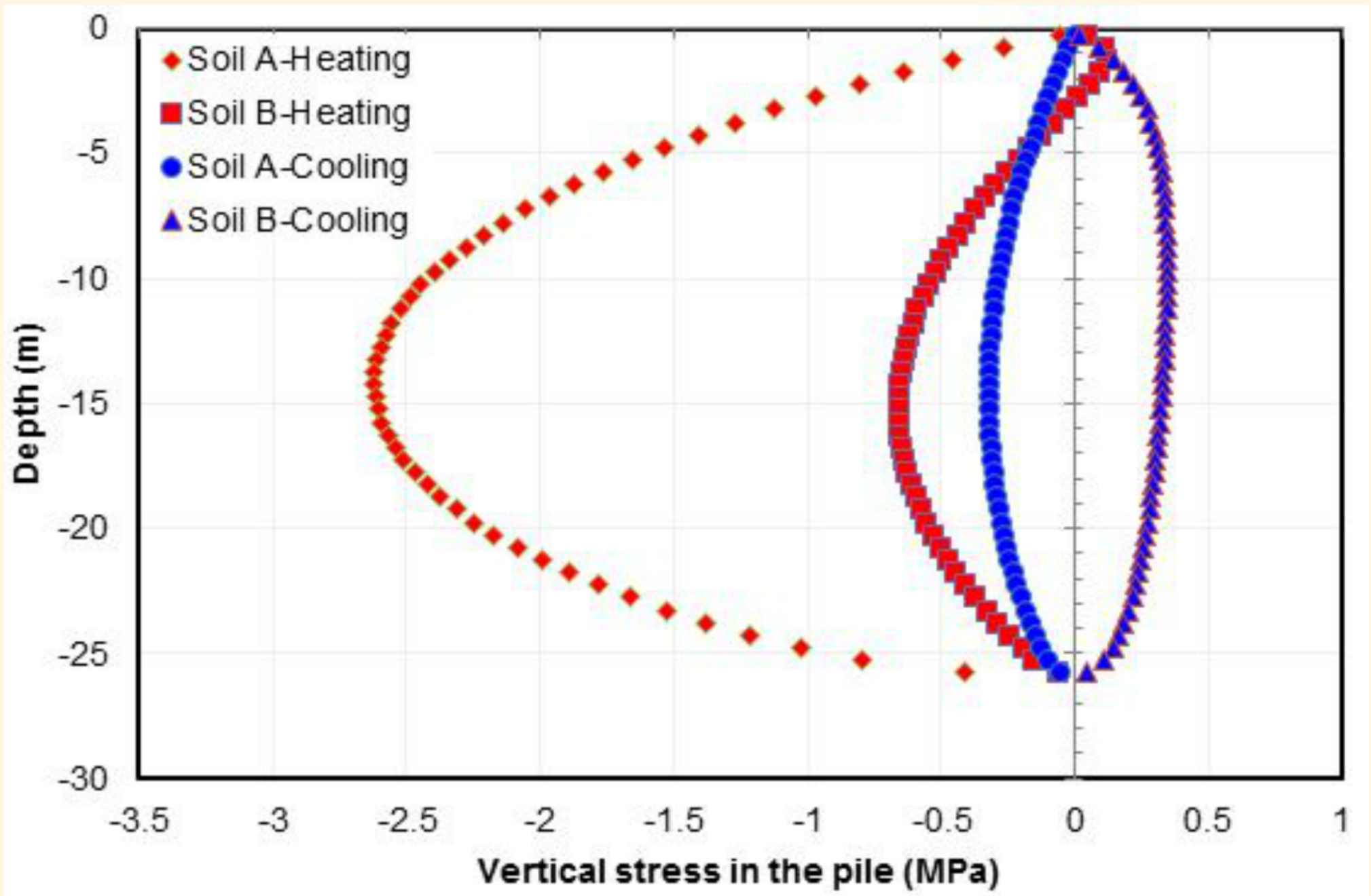


Figure 12. Vertical stress in the pile with depth at 21 and 3 degree Celsius

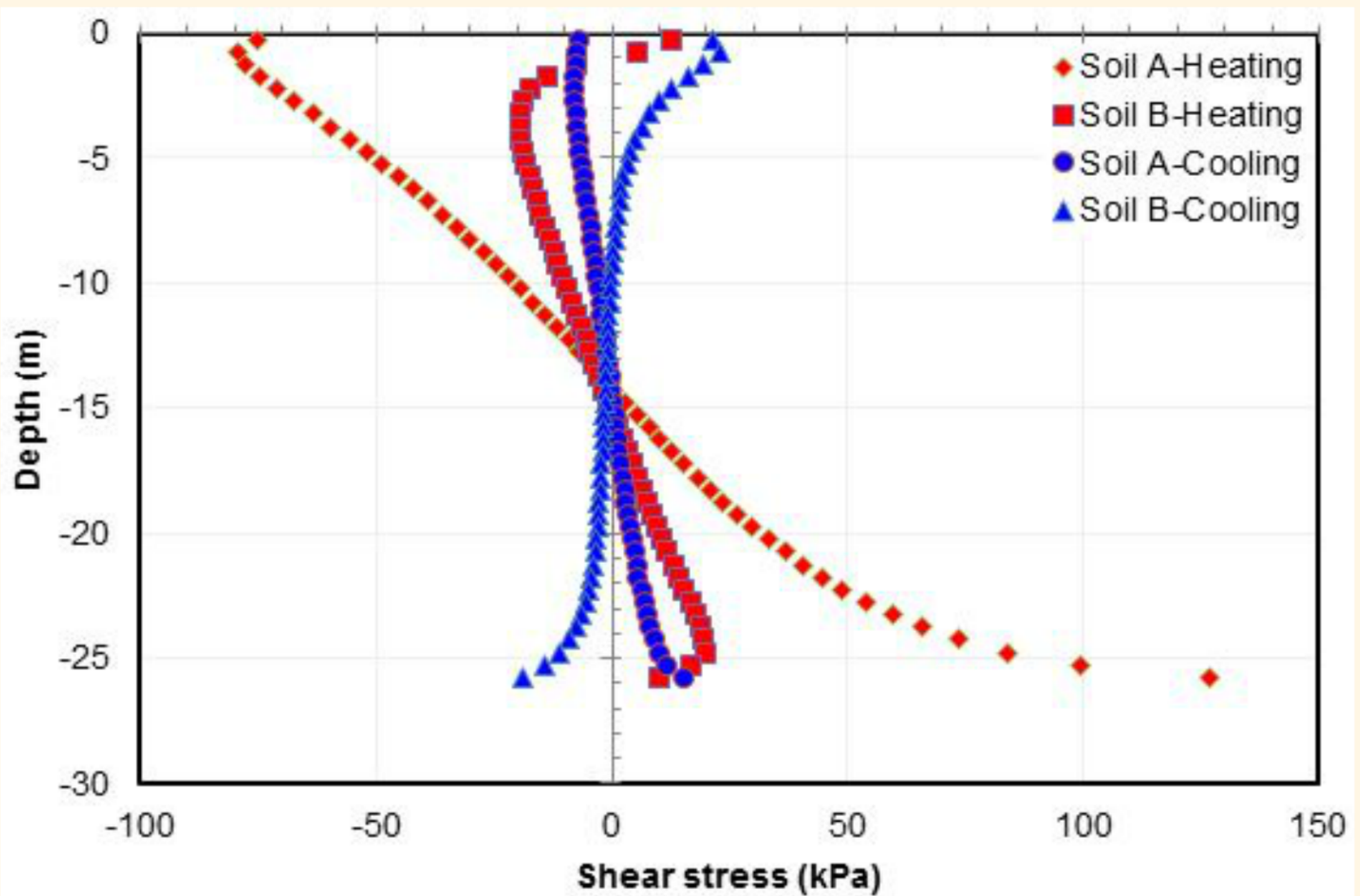


Figure 13. Shear stress next to pile with depth at the end of heating and cooling phases

In layered system

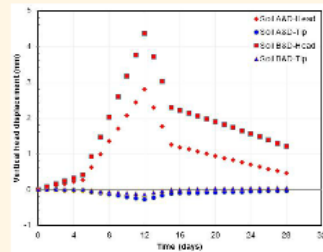


Figure 14. Vertical displacement of the pile head and toe during thermal loading

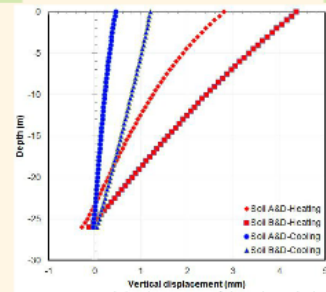


Figure 15. Vertical displacement of the pile with depth at 21 and 3 degree Celsius

STRESSES AND STRAINS

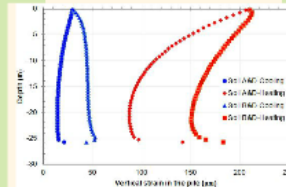


Figure 16. Vertical strains in the pile with depth at 21 and 3 degree Celsius

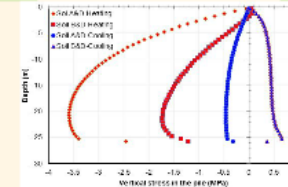


Figure 17. Vertical stress in the pile with depth at 21 and 3 degree Celsius

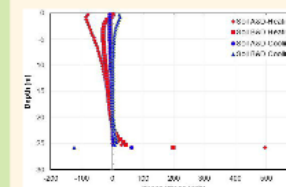
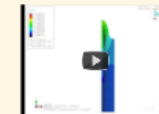


Figure 18. Shear stress next to pile with depth at the end of heating and cooling phases



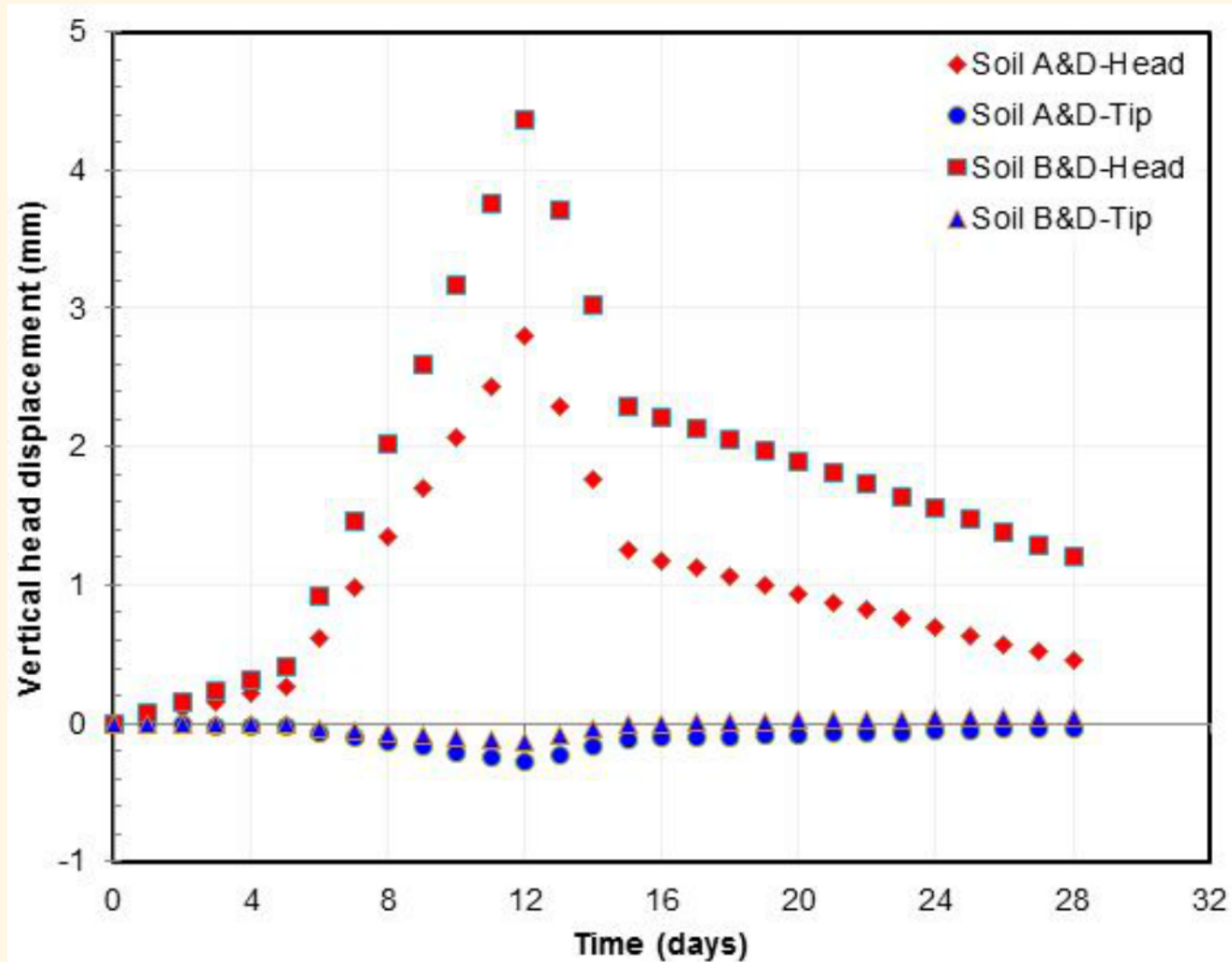


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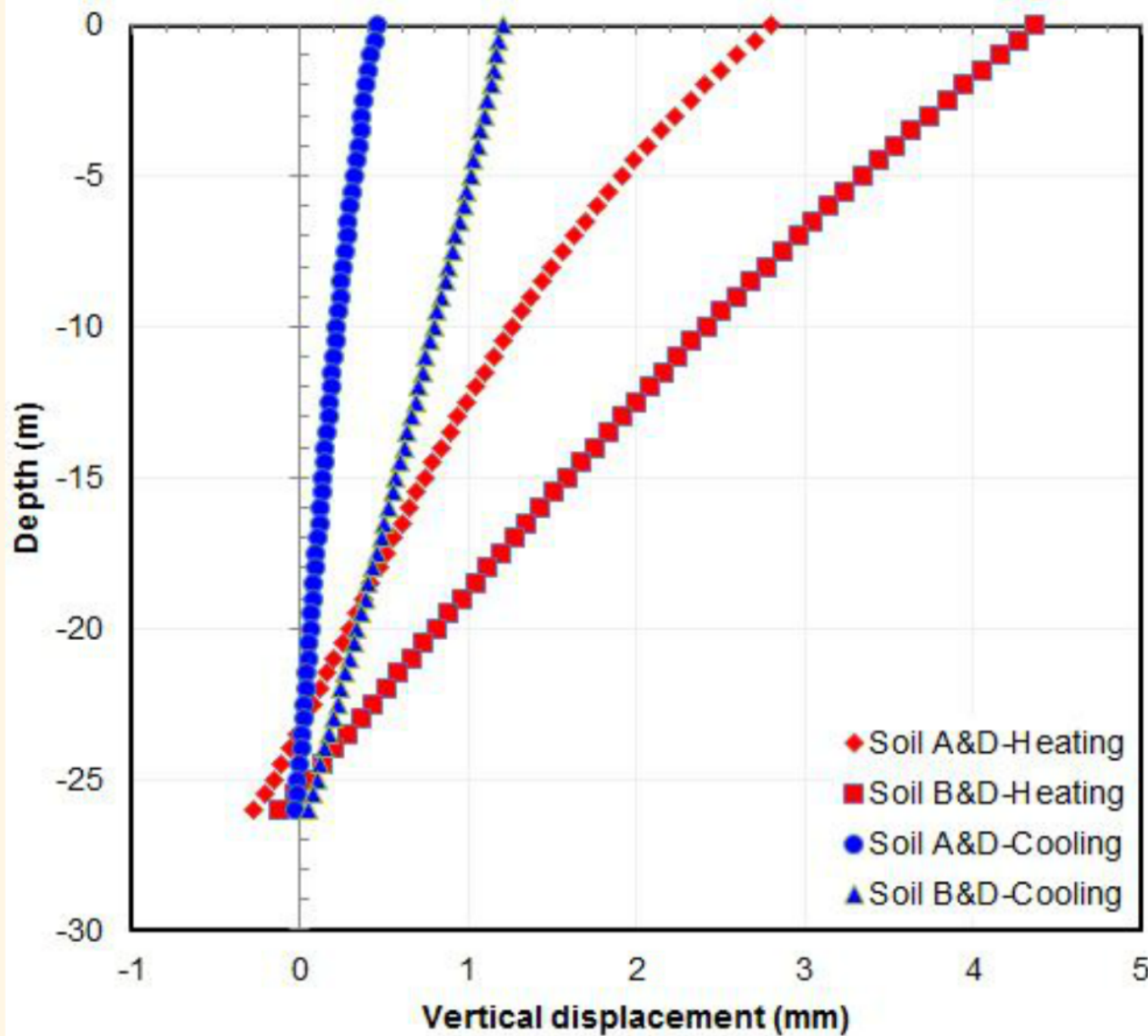


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STRESSES AND STRAINS

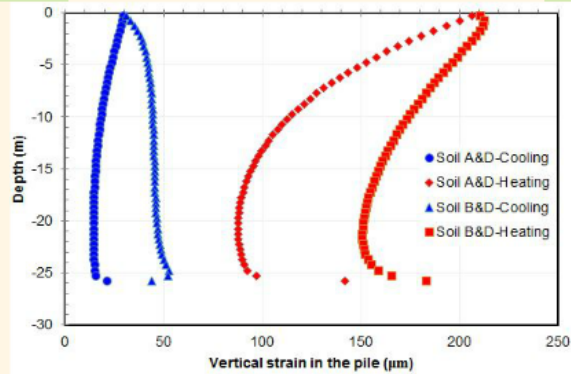


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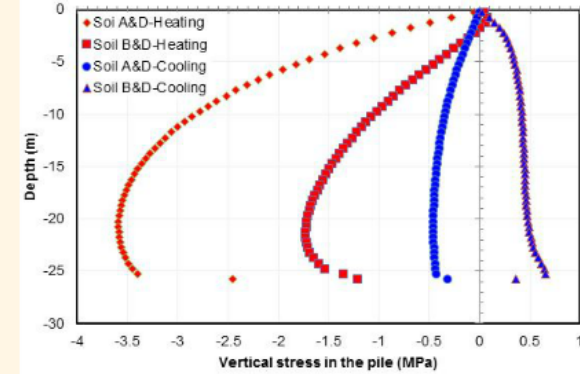


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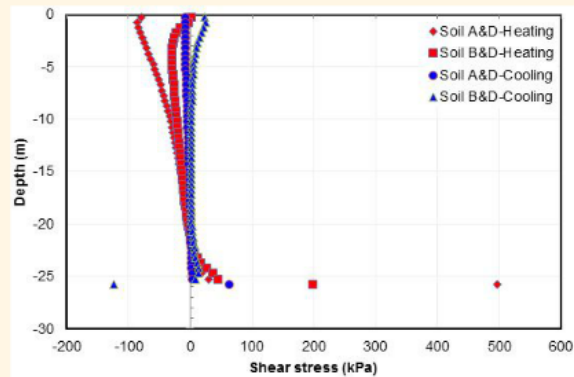
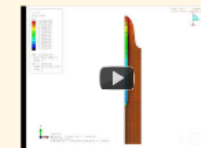
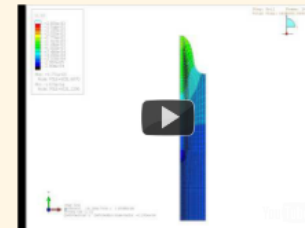


Figure 18. Shear stress next to pile with depth at the end of heating and cooling phases



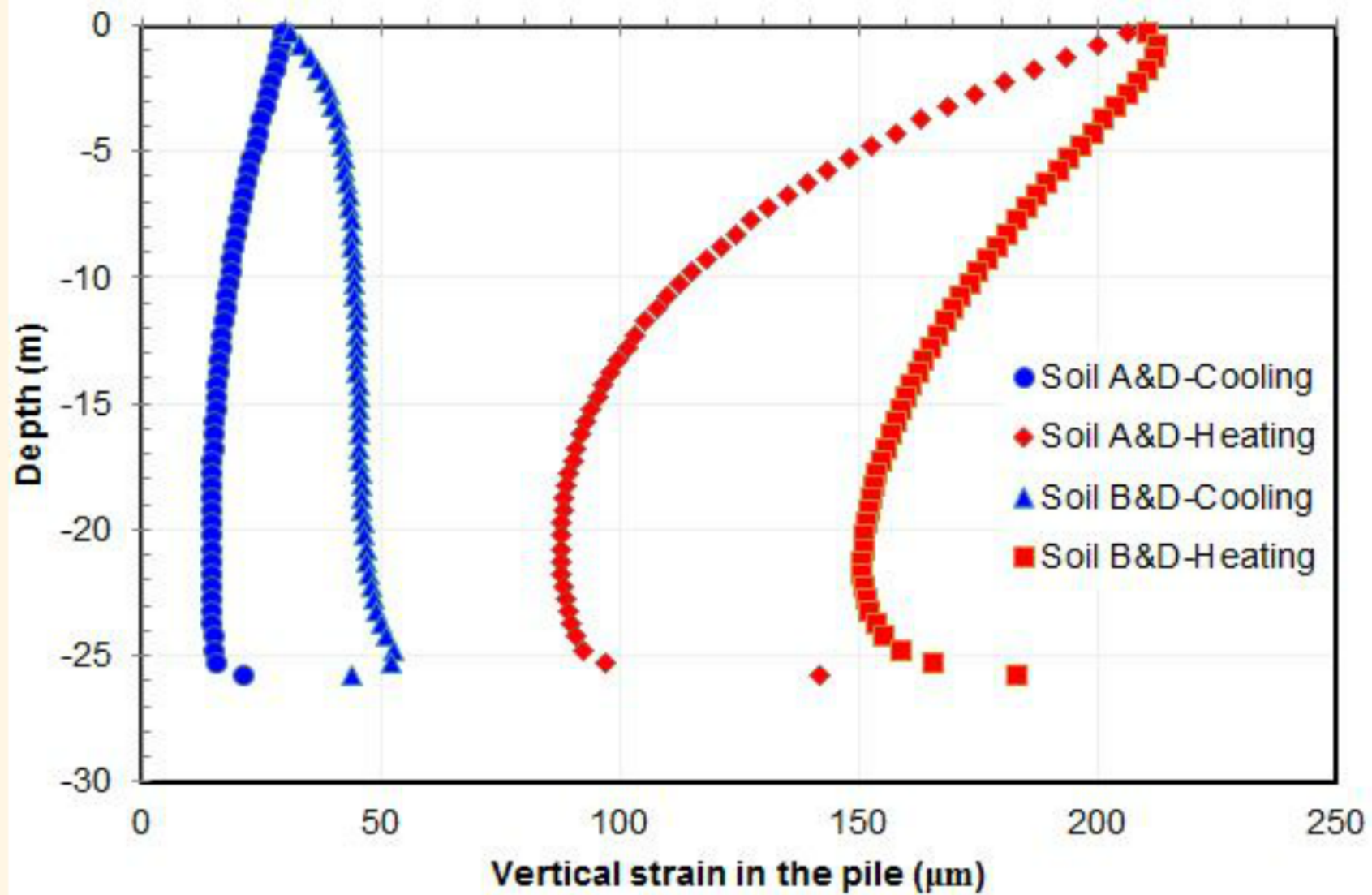


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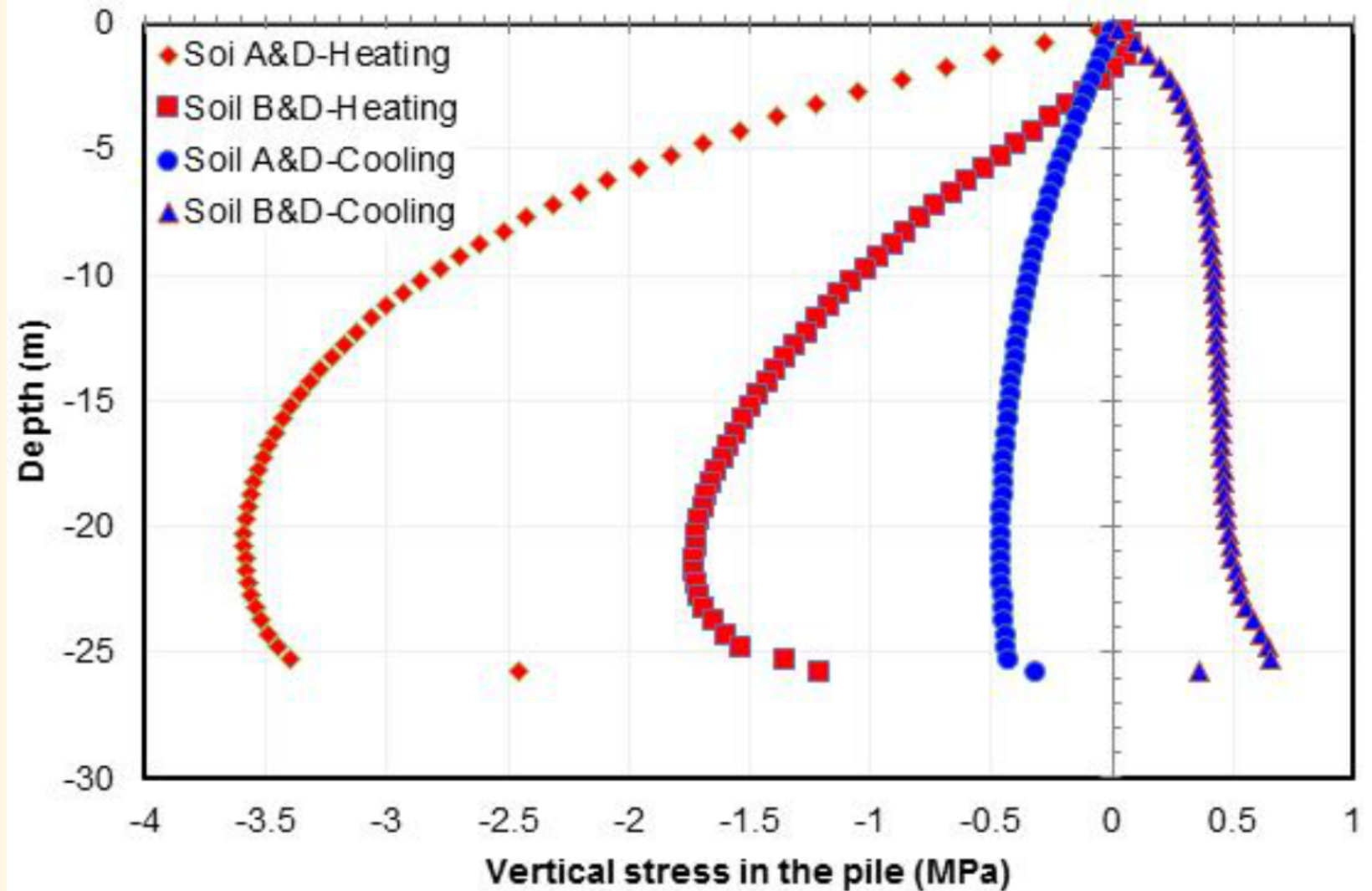


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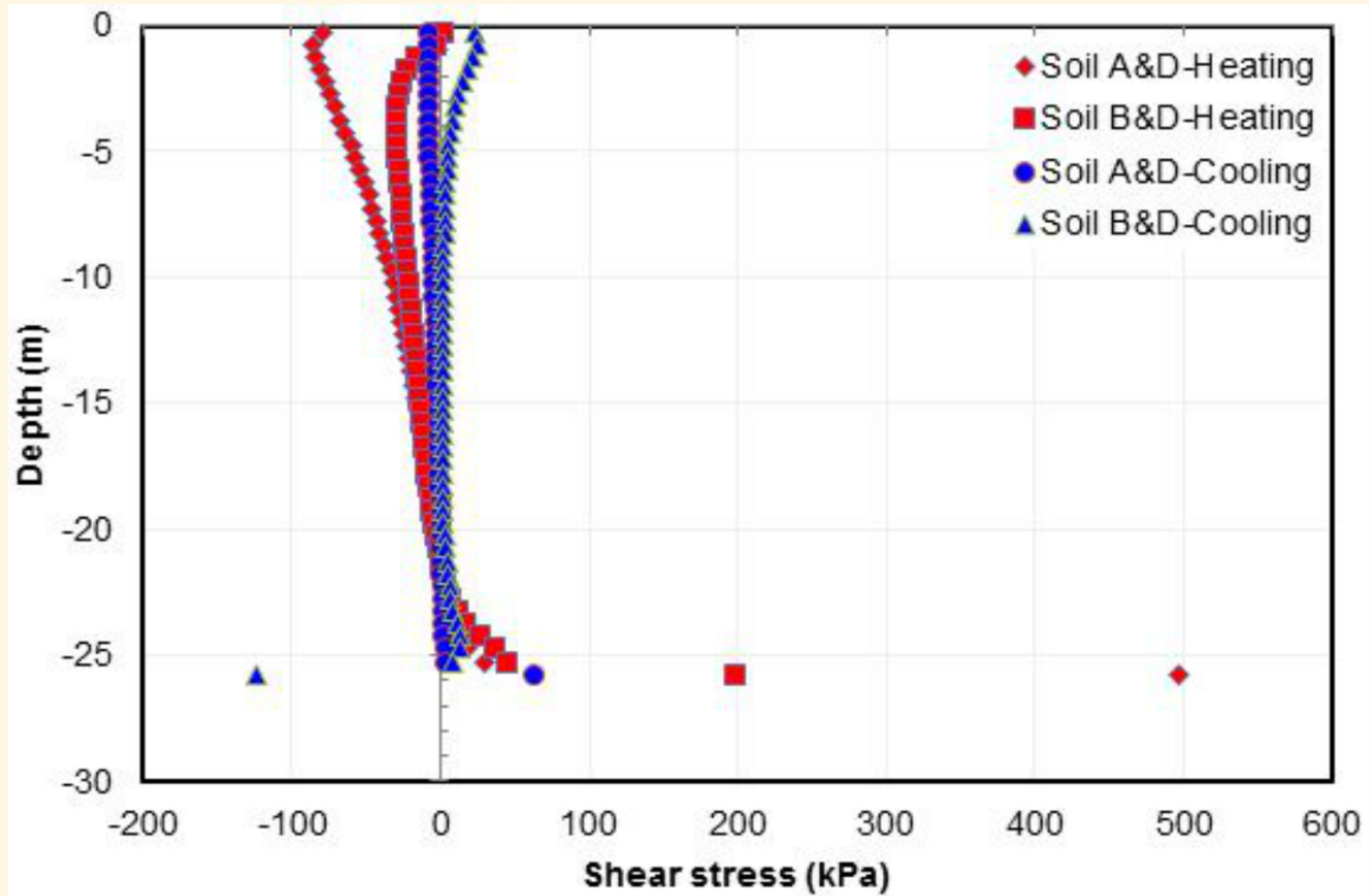
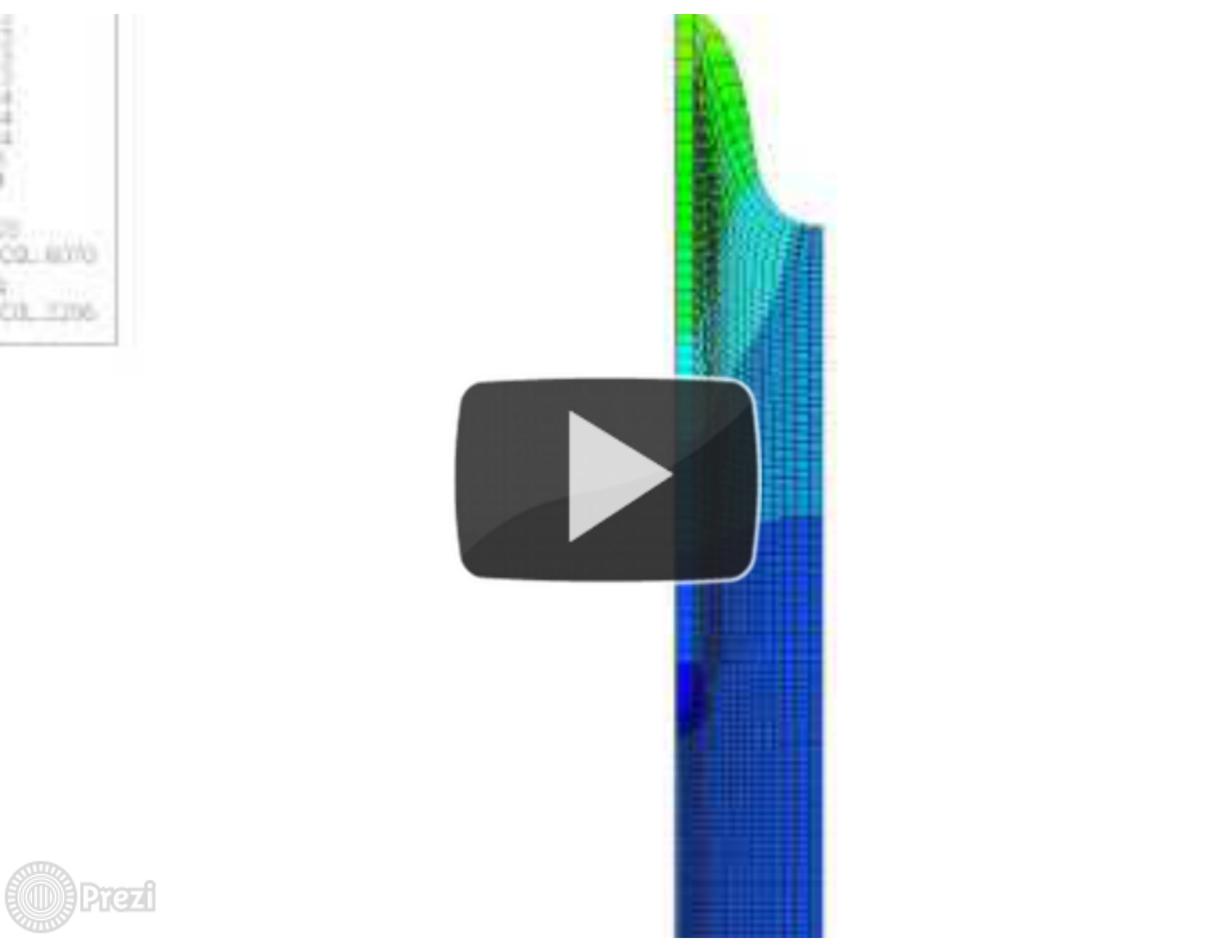
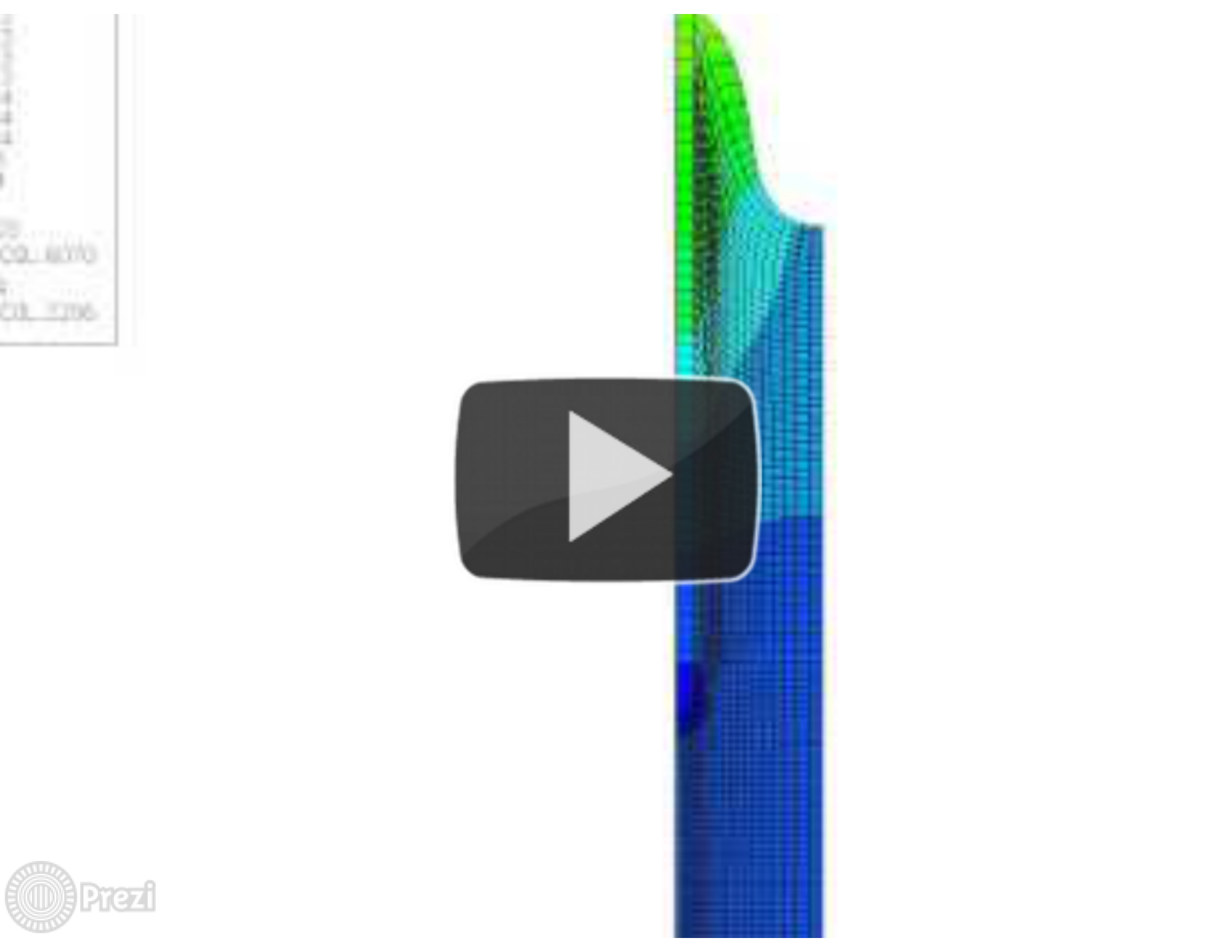
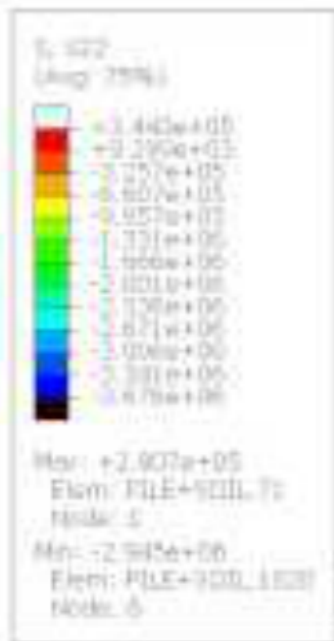
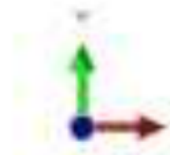


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Step: 501 Frame: 13
Total Time: 1.129300e+09



Step: 501
Frame: 13
Total Time: 1.129300e+09
Deflected (S: S22) Deformation Scale Factor: +1.00e+00

YouTube

Conclusions

- Environmentally friendly and sustainable alternative energy source.
- Soil properties and soil layering at the site influence stresses, strains and displacement of HEP.
- Max thermal axial strains occurred at the pile head at the end of heating period.
- Heating induced additional compressive stresses in the pile while increasing mobilized shear stresses in the surrounding soils.
- Heating induced negative skin friction in the upper portion of the pile.
- Tensile stresses developed in the pile during cooling phase have been well within accepted limits for the reinforced concrete.

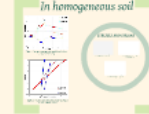
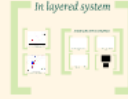
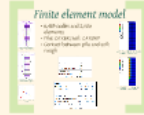
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Thank you!

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